Standard Library Improvements

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Outline

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- Reflection Library Module
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  - Inspecting Fields
- Improvements to the Random Standard Module
- JAMA: Linear Algebra module
- FileSystem/Path Module Improvements
- I/O Improvements for JSON
- Other I/O Improvements
- Spawn Module Improvements
- Other Library Improvements
Standard Library vs. Package Modules
Background:
- Most user-facing libraries we’ve distributed have lived in one directory:
  $CHPL_HOME/modules/standard/

This Effort:
- Over time, it’s seemed that we have two classes of standard modules:
  - standard library modules
    - those that any Chapel implementation ought to support
    - e.g., ‘Math’, ‘FileSystem’, ‘Reflection’, …
  - package modules
    - those representing community codes or optional features
      - e.g., ‘FFTW’, ‘LAPACK’, ‘HDFS’, …
    - ultimately these should be managed by a distributed package manager
  - we’ve also moved some immature libraries here for the time being
    - e.g., ‘Sort’, ‘Search’, ‘Norm’, …
Libraries vs. Packages: Status and Next Steps

Status:

- Split standard modules into two directories, along with their docs:
  - libraries: $CHPL_HOME/modules/standard
  - packages: $CHPL_HOME/modules/packages
  - see [http://chapel.cray.com/docs/latest/modules/packages.html](http://chapel.cray.com/docs/latest/modules/packages.html)
  - Compiler populates module search path with both directories

Next Steps:

- Improve immature packages and promote to standard library
- Create a distributed package manager (see “Ongoing Efforts” slides)
Reflection Library Module
Reflection: Background and This Effort

Background:

- Chapel already supports generic programming:
  - where clauses, type functions, param functions, and param for-loops
- Yet, it can also be useful to make explicit queries
  - about procedures or methods that are available
  - about fields in records or classes
- Such introspection has proven valuable in C++
  - SFINAE and enable-if in C++
- Chapel’s internal modules already make such queries
  - but not in ways that were intended for end-users

This Effort:

- Provide user-facing introspection in a new ‘Reflection’ module
  - inspecting which procedures or methods are available
  - inspecting fields in records or classes
Reflection: Querying Function Resolution
Can Resolve: Motivation and This Effort

**Motivation:**
- Suppose we're writing a sorting library
  - Uses a `compare` routine, where `compare(a,b)` returns an int that’s…
    - `< 0` if `a < b`
    - `== 0` if `a == b`
    - `> 0` if `a > b`
- For usability reasons, we would like the library to
  - optionally allow `compare` to be written as a method
  - fall back on calls to `<` if no `compare` method/function is provided

**This Effort:**
- Adds `canResolve` and `canResolveMethod` functions
Can Resolve: Library Example

```java
use Reflection;

private proc do_compare(a, b) {
    if canResolveMethod(a, "compare", b) {
        // use a.compare(b) if possible
        return a.compare(b);
    } else if canResolve("compare", a, b) {
        // if not, use compare(a,b)
        return compare(a, b);
    } else {
        // otherwise, fall back on a version using <
        if a < b then
            return -1;
        else if b < a then
            return 1;
        else return 0;
    }
}
```
record MyRecord {
    var x:int;
}

// Client of sorting library could provide
// any or all of these comparison routines.
proc MyRecord.compare(b: MyRecord) {
    return this.x - b.x;
}
proc compare(a: MyRecord, b: MyRecord) {
    return a.x - b.x;
}
proc <(a: MyRecord, b: MyRecord) {
    return a.x < b.x;
}
Can Resolve: Impact, Status, and Next Steps

**Impact:**
- Enables generic libraries to respond to what functions are available

**Status:**
- Implemented, documented, fully functional

**Next Steps:**
- Replace current internal uses of ‘tryToken’ with ‘canResolve’
  - this was the previous (and weaker) internal means of making such choices
- Get user feedback on ‘canResolve’
Reflection: Inspecting Fields
Inspecting Fields: Motivation

Motivation:

- Suppose that we're writing an I/O library with a particular format, e.g.
  - JSON
  - BSON
  - XML
  - MessagePack
  - YAML
  - Protocol Buffers
  - Apache Thrift

- For usability reasons, want the library to work with any record or class

This Effort:

- Adds field introspection routines
  - numFields, getFieldName, getField, getFieldIndex, hasField
use Reflection; use Types;

private proc do_outputYaml(obj:?t, indent:string) {  
  for param i in 1..numFields(t) {     // param loop over fields  
    var field = getField(obj, i);     // query value of i\textsuperscript{th} field  
    var fieldName = getFieldName(t, i); // query name of i\textsuperscript{th} field  
    if isString(field) || isNumeric(field) {   
      // Output numbers and strings directly  
      writeln(indent, fieldName, "\: ", field);  
    } else if isRecord(field) || isClass(field) {   
      // Recurse to output a record or class.  
      writeln(indent, fieldName, "\: ");  
      do_outputYaml(field, indent + "    ");  
    } else compilerError("unhandled type ", field.type:string);  
  }  
}  

proc outputYaml(obj) {  
  writeln("---"); do_outputYaml(obj, """); writeln("...");}

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Inspecting Fields: Usage Example

```javascript
var r = new Invoice(number=22, total=135.17,
                     new Customer("Dorothy", "Gale"));
outputYaml(r);

record Customer {
    var first_name: string;
    var family_name: string;
}
record Invoice {
    var number: int;
    var customer: Customer;
    var total: real;
}
```

```yaml
---
number: 22
customer:
    first_name: Dorothy
    family_name: Gale
total: 135.17
...
Inspecting Fields: Impact, Status, and Next Steps

**Impact:**
- Enables generic libraries to adapt to fields in records and classes

**Status:**
- Implemented, documented
- `getField` does not currently return a mutable value
  - primitive can be used for now as a workaround
  - `getFieldRef` implemented but didn't make it into v1.13 (on master now)

**Next Steps:**
- replace uses of primitives in ChapelIO with Reflection module routines
- consider changing these functions to methods / type methods
Improvements to the Random Standard Module
Random: Background

- <= 1.12 only had NPB Random Number Generator (RNG)

- NPB RNG has issues
  - it’s a 46-bit Linear Congruential Generator (LCG)
  - it only supports generating real(64), imag(64), complex(128)
  - it’s implemented in terms of double-precision arithmetic
    - i.e., has lower than ideal performance if converting reals to integers
  - it’s not suitable for Monte Carlo*
  - it fails 41/144 statistical tests in TestU01's Crush suite

- Yet, the NPB RNG supports *jump-ahead*
  - supports deterministic parallel RNG use cases

- Have long intended to address these issues
  - Users have requested better Random support as well

* = see Click, Kaminski, and Liu, “Quality of random number generators significantly affects results of Monte Carlo simulations for organic and biological systems”
Random: Some other RNGs

- **Mersenne Twister**
  - popular
  - used in Python
  - we didn’t find a version that supported jump-ahead that we liked
    - came with disclaimers
    - raised licensing challenges (GPL, vague/missing licenses)

- **PCG: Permuted Congruential Generator**
  - reasonably new
  - supports jump-ahead
  - simple implementation
  - C implementation available with permissive license (Apache)
Random: This Effort

- **Implemented PCG RNG purely in Chapel code**
  - it was simple enough not to require wrapping the C library
  - main PCG RNG has 64 bits of state and generates 32 bits at a time
  - generate >32 bits by splicing RNGs with different increments
  - Adds functionality to the C PCG implementation
    - generates real values (via multiplying by $2^{**-64}$)
    - generates bounded integer values in way that supports jump-ahead

- **Refactored Random standard module**
  - Parallel `RandomStream` available with either NPB or PCG RNG
  - PCG is now the default
  - Low-level PCG module is also available, providing interface like C’s

- **Added new functionality**
  - `shuffle`, `permute`, generate random integer

- **Documented `RandomStream.iterate`**
Random: Impact

- **Tested statistical properties with TestU01's Crush suite:**
  - NPB failed 41/144 tests for real(64)
  - PCG passed all tests for real(64), uint(64)
  - PCG failed 1 test for real(32)
    - as does the C PCG implementation with the same seed

⇒ **PCG offers much improved statistical properties**
Random: Impact

- **PCG is faster and more flexible than NPB**
  - 1.4x when generating doubles; able to generate integers directly

![Bar chart comparison between PCG and NPB](chart.png)
Random: Impact

Status:
- PCG RNG is the new default in 1.13
- Better performance and statistical properties
- Integer output supported

Next Steps:
- Improve API based on review, user feedback, Chapel improvements
  - e.g., leader-follower improvements required to zipper RNGs naturally
- Support additional RNGs as necessary / desired
JAMA: Linear Algebra module
(contributed by Chris Taylor)
JAMA: Background and This Effort

Background:
- JAMA: Linear Algebra package originally for Java
  - Aimed at creation/manipulation of real, dense matrices
  - Developed by MathWorks and NIST
  - Ported to Chapel
- Focuses on 5 fundamental matrix decompositions:
  - Cholesky – for symmetric, positive definite matrices
  - LU – for rectangular matrices
  - QR – for rectangular matrices
  - Eigenvalue – for symmetric and nonsymmetric square matrices
  - Singular – for rectangular matrices

This Effort:
- Ported JAMA to Chapel
JAMA: LU Decomposition Example

Example usage:

```
use LinearAlgebraJama;

var A = ...; // Initialize A. We'll compute L and U from A such that L*U = A
var LU = A.lu();
var L = LU.getL();
var U = LU.getU();
...
// Using L and U, solve Ax = b for x given b (for instance)
```

\[
\begin{pmatrix}
    a_{11} & a_{12} & a_{13} \\
    a_{21} & a_{22} & a_{23} \\
    a_{31} & a_{32} & a_{33}
\end{pmatrix}
= 
\begin{pmatrix}
    l_{11} & 0 & 0 \\
    l_{21} & l_{22} & 0 \\
    l_{31} & l_{32} & l_{33}
\end{pmatrix}
\begin{pmatrix}
    u_{11} & u_{12} & u_{13} \\
    0 & u_{22} & u_{23} \\
    0 & 0 & u_{33}
\end{pmatrix}
\]
Example 2:

```java
use LinearAlgebraJama;

var A = ...; // Initialize A. If symmetric, V*D*V' = A
var Eig = A.eig();
var D = Eig.getD(); // an eigenvalue matrix
var V = Eig.getV(); // an eigenvector matrix
...
// Using D and V, find the inverse of A (for instance)
```
JAMA: Next Steps

● Create online documentation
  ● Current document comments are javadoc style rather than chpldoc

● Connect to LAPACK and BLAS modules
  ● Once BLAS module routines finished

● Design/implement sparse matrix solution

● Use as starting point for computer algebra module
  ● Similar to Python’s Theano, NumPy
  ● Aimed at dense vector/matrix computations
  ● Also would make use of LAPACK/BLAS routines
FileSystem/Path Module Improvements
FileSystem/Path: Background and This Effort

**Background:**
- Recent releases added *FileSystem* and *Path* modules
  - *FileSystem* was nearly complete, but missing a few routines
  - *Path* was mostly empty, waiting on strings to mature

**This Effort:**
- Complete *FileSystem*
- Continue with *Path* now that strings are in good shape
FileSystem/Path: Status and Next Steps

**Status:**

**FileSystem:** Finished remaining routines
- `rmTree()`: remove directory and contents
- `moveDir()`: move directory and contents to new location

**Path:** Added a few more routines
- `basename()`: last component of given path
- `dirname()`: all but last component of given path
- `splitPath()`: divide path into (dirname, basename)
- 10 functions remain unimplemented
  - `absPath()`, `joinPath()`, etc.

**Next Steps:** complete remaining *Path* routines
Spawn Module Improvements
Spawn Module Improvements

**Background:** Added ‘Spawn’ standard module in v1.12
- had a bug where `communicate()` did not function correctly
- had several bugs related to interrupted system calls
- did not include functions for sending signals to subprocesses

**This Effort:** Improved the Spawn module
- fixed `communicate()`
- made `wait()` optionally call it when `buffer=true` via new argument:
  ```python
  proc subprocess.wait(out error: syserr, buffer=true) ...
  ```
- fixed problems with interrupted system calls
- added support for sending signals (contributed by Nick Park)

**Impact:** Spawn module is much more stable and usable

**Next Steps:** Write more programs using the Spawn module!
I/O Improvements for JSON
JSON Improvements: Background & This Effort

Background:
- I/O module supports `writeln`, `writef`, …
- during v1.12, there was an ongoing effort to improve JSON I/O

This Effort:
- Improved JSON support with `~` in format strings to skip fields
  - see example on following slides
Example Tweet in JSON format

- Tweets have 34 top-level fields
  - including nested structures containing additional fields

```json
{
  "coordinates": null,
  "created_at": "Fri Oct 16 16:00:00 +0000 2015",
  "favorited": false,
  "truncated": false,
  "id_str": "28031452151",
  "entities": {
    "urls": [
      {
        "expanded_url": null,
        "url": "http://chapel.cray.com",
        "indices": [69, 100]
      }
    ],
    "hashtags": [],
    "user_mentions": [
      {
        "name": "Cray Inc.",
        "id_str": "23424245",
        "id": 23424245,
        "indices": [25, 30],
        "screen_name": "cray"
      }
    ],
    "in_reply_to_user_id_str": null,
    "text": "Let's mention the user @cray -- here is an embedded url .......... http://chapel.cray.com",
    "contributors": null,
    "id": "28039652140",
    "retweet_count": null,
    "in_reply_to_status_id_str": null,
    "geo": null,
    "retweeted": false,
    "in_reply_to_user_id": null,
    "user": {
      "profile_sidebar_border_color": "C0DEED",
      "name": "Cray Inc.",
      "profile_sidebar_fill_color": "DDEEF6",
      "profile_background_tile": false,
      "profile_image_url": "http://a3.twimg.com/profile_images/2342452/icon_normal.png",
      "location": "Seattle, WA",
      "created_at": "Fri Oct 10 23:10:00 +0000 2008",
      "id_str": "23502385",
      "follow_request_sent": false,
      "profile_link_color": "0084B4",
      "favourites_count": 1,
      "url": "http://cray.com",
      "contributors_enabled": false,
      "utc_offset": -25200,
      "id": "23548250",
      "profile_use_background_image": true,
      "listed_count": 23,
      "protected": false,
      "lang": "en",
      "profile_text_color": "333333",
      "followers_count": 1000,
      "time_zone": "Mountain Time (US & Canada)",
      "verified": false,
      "geo_enabled": true,
      "profile_background_color": "C0DEED",
      "notifications": false,
      "description": "Cray Inc",
      "friends_count": 71,
      "profile_background_image_url": "http://s.twimg.com/a/2349257201/images/themes/theme1/bg.png",
      "statuses_count": 302,
      "screen_name": "gnip",
      "following": false,
      "show_all_inline_media": false,
      "in_reply_to_screen_name": null,
      "source": "web",
      "place": null,
      "in_reply_to_status_id": null
    }
  }
}
```
JSON Improvements: Reading Tweet subsets

// define Chapel records whose fields reflect only 
// the portions of the JSON data we care about

record TweetUser {
    var id: int;
}

record TweetEntities {
    var user_mentions: list(TweetUser);
}

record User {
    var id: int;
}

record Tweet {
    var id: int,
        user: User,
        entities: TweetEntities;
}

proc process_json(...) {
    var tweet: Tweet;

    while true {
        // “%~jt” format string:
        //     j: JSON format
        //     t: any record
        //     ~: skip other fields
        got = logfile.readf("%~jt",
                            tweet,
                            error=err);
        if got && !err then
            handle_tweet(tweet);
        if err == EFORMAT then ...
        if err == EEOF then break;
    }
}
JSON Improvements: Impact and Next Steps

**Impact:**
- JSON support is improved in version 1.13

**Next Steps:**
- Support formatting extensions to `channel`
  - since not all formats will be supported directly as JSON is
Other I/O Improvements
Other I/O Improvements

- HDFS package now supports libhdfs3 (contributed by Chris Taylor)
- Removed Reader and Writer types in favor of channels
- Made readbits/writebits accept any integral argument
- List module now supports JSON format
- Default I/O routines now ignore ‘param’ fields
- channels now support an isClosed() method
Other Library Improvements
Other Library Improvements

- **Time.sleep()** now optionally supports a unit argument  
  (contributed by Nick Park)

- **exit()** can now be called without arguments  
  (contributed by Kushal Singh)

- Also, aforementioned library routines for strings:  
  [http://chapel.cray.com/docs/1.13/modules/internal/String.html](http://chapel.cray.com/docs/1.13/modules/internal/String.html)
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